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# Element Modeling of Masonry Wall With Opening Under Lateral Force

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**Abstract:** Three-dimensional Finite Element Model for Masonry Wall with openings under lateral force using ABAQUS software. Finite element model verification with an experiment masonry wall in the laboratory without openings. The load-displacement relationship of finite element model is well agreed with experimental results. Parametric studies conducted on masonry wall with openings to investigate the influence of an area of openings. This research aimed to investigate the behavior of Masonry Walls with openings under lateral force. The result showed that the increase of the area of openings decreases stiffness and strength of masonry. It is also well observed from the result that lateral resistance of masonry will decrease for each area of the opening wall.

**Keywords:** Finite element; ABAQUS Software; Masonry wall with an opening; Lateral Force.

## 1. Introduction

Indonesia is located in the earthquake zone, has caused many buildings to suffer damage because of the earthquake. When a building receives an earthquake, the biggest damage is nonengineered structures. A masonry wall is nonengineered structures which in the construction is often not calculated. In a masonry wall, there is an opening which has a reduced area of the wall, due to the placement of doors or windows. Reduced the area of the wall will affect the behavior of the masonry wall.

Research on masonry that receives the lateral force has been done, Hakas [1] researched the prediction lateral in a plane through changes natural frequency and the damping of the structure of Masonry Wall ½ brick with mortar 1 Pc: 4 Lime: 10 Sand. While Satyarno [2] researched Masonry strength due to static and cyclic load. The masonry walls with openings have been Research by Archana [3] researched the effect of openings and the ratio of openings to masonry walls on concrete frames. Whereas Bashar [4] researched the behavior of structures with opening walls that received Compressive Loading. Putra [5] researched the effect of the location of openings on the performance of confined masonry walls with cyclic loads.

The Finite Element Method has been widely used by researchers to analysis Masonry walls, the researchers using the Finite Element Method in analyzing Masonry walls such as Stavridis [6] used Finite Element to determine the behavior of concrete masonry walls, Mohyeddin [7] modeled by using the ANSYS program, Alchaar [8] and D'ayala [9] used the ALGOR program to model Finite Element, Stavridis [10] modeled concrete masonry walls provided with seismic loads.

ABAQUS software has been widely used in the model of finite Element modeling on the Masonry wall. Chen [11] simulate damage to Masonry walls using the Abaqus program. Maeillyta [12] model the Masonry walls with ABAQUS openings, Moghadam [13] used the ABAQUS program to model the Masonry walls.

The aims of this research are to comprehensively investigate the behavior of Masonry Walls with an opening under lateral force (1) 3-dimensional modeling using ABAQUS Software. (2) Find the load and displacement Curve, (3) Find the damage of masonry wall with variations of openings.

## 2. Modeling of Finite Element

Masonry walls are modeled using ABAQUS software, geometric details, loads and materials applied to Abaqus software described below:

### 2.1. Geometric and load modeling

Model created with scale 1:1 with dimensions of 3 x 3 x 0.15 m are placed on a reinforced concrete sloof. Finite Element modeling adapted using the experiments of Hakas (2017) as verification of finite element model.

A masonry wall with mortar was modeled with a homogeneous material. Used constrain tie to connect between the Masonry walls and concrete. Reinforcement is modeled using 2 nodes, linear truss element and embedded in concrete material performed, measure displacement in line with the lateral load and use un-restrain in some direction of load and restrain in another direction. Fig. 1 shows the meshing in modeling Finite Element and Fig. 2 shows apply lateral force in a solid Masonry wall

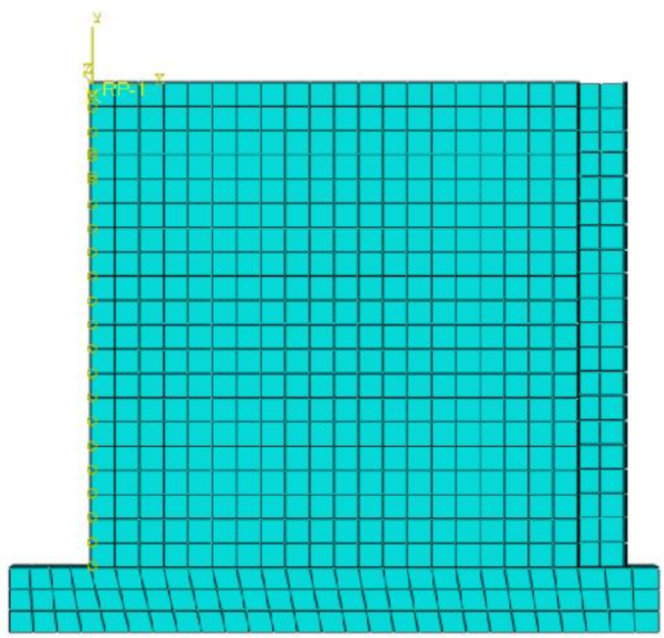

**Fig 1**. Meshing Finite element Model of Solid Masonry wall

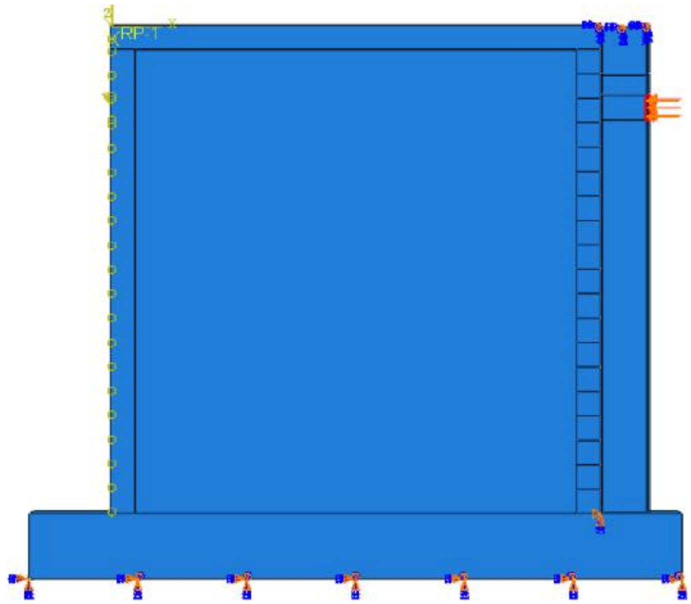

**Fig 2**. Apply lateral force in a solid Masonry wall

### 2.2. The material in Abaqus Model

Data Material of concrete and reinforcing for the modeling of finite element used data from the experiments of Hakas (2017). Material data used can be explained as follows:

#### 2.2.1. Concrete

Concrete used for beams and columns have compressive strength 15.6142 MPa. Stress-strain curve for concrete compressive strength calculated based on BS EN 1992-1-1 [14] and for tensile strength based on Wang [15] (See Fig. 3 and fig. 4). Other parameters used in concrete are Density = 2400 kg/m3, modulus of Elasticity = 18569.46 MPa, Poison Ratio 0.2, Dilation Angle = 300, Flow potential eccentricity = 0.1, Ratio of initial equi-biaxial compressive yield stress to initial uni-axial compressive yield stress = 1.16, Ratio of second stress invariant = 0.667, Viscosity parameter = 0.005.

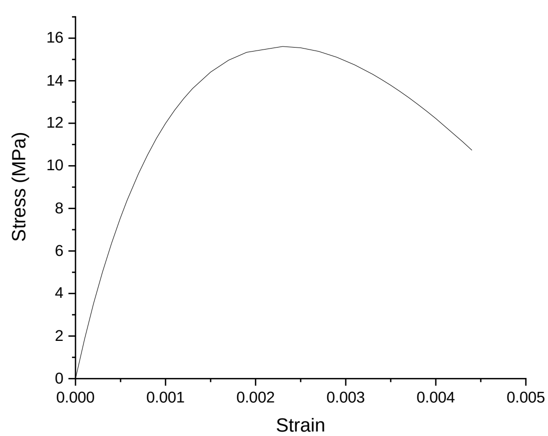


**Fig 3**. Constitutive model in ABAQUS for the Compressive strength of Concrete -BS EN 1992-1-1 [14]

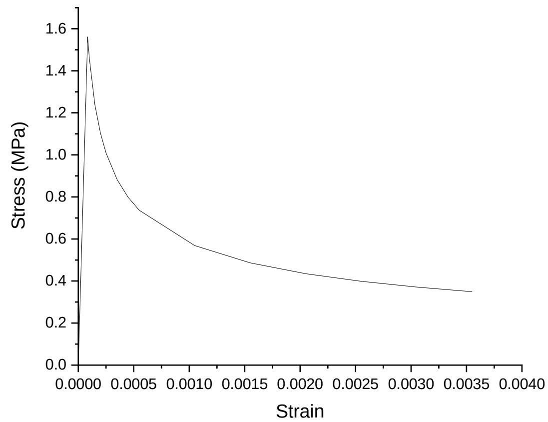


**Fig 4**. Constitutive model in ABAQUS for the tensile strength of concrete – Wang [15]

### 2.2.2. Steel for reinforcement

Steel for reinforcement used grade U39 for the diameter of 8 and a diameter of 6. Fig. 5 and Fig. 6 shows the results of the tensile test for the diameter of 8 and 6. Other parameters used in steel reinforcement materials are: Density = 7850 kg/m3, Modulus of Elasticity = 197724.7 MPa, Poisson's ratio = 0.3

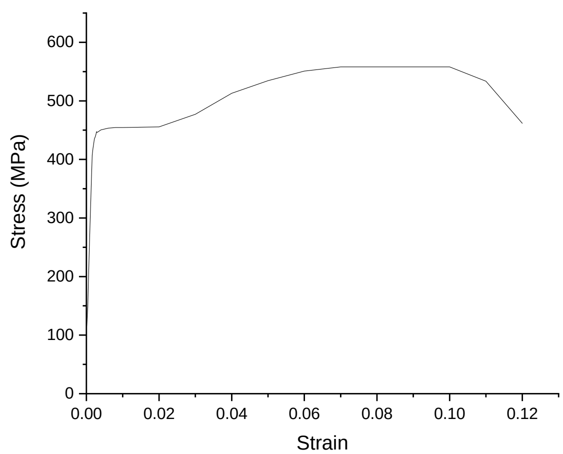


**Fig. 5.** Stress-strain curve diameter 8 mm (Hakas 2017)

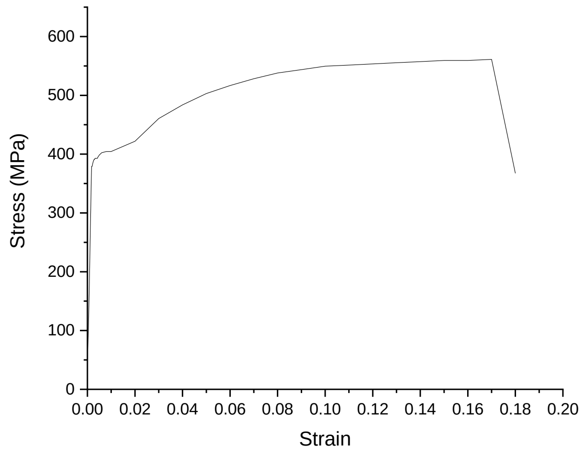


**Fig. 6.** Stress-strain curve diameter 6 mm (Hakas 2017)

#### 2.2.3. Masonry

The compressive strength of the masonry walls was calculated using the Equations of T. Paulay [16]. The formula use data of the size of a brick, the distance between the thicknesses of the mortar, the compressive strength of brick, the compressive strength of mortar. Equations used for calculation are:

$$f'_m = \emptyset\left\lfloor x f'_p + (1-x) f'_y \right\rfloor \quad (1)$$

and

$$f'_p = f_y = \frac{f'_c \ (f'_t \ + \alpha f'_j)}{U_u \ (f'_t \ + \alpha f'_c \ )} \quad (2)$$

Where:

f'm = compressive strength of Masonry wall (MPa)

Table 1. The compressive strength of masonry

| Dimension of Brick | | | Gap of 2 BrickS | Mortar thickness | strength of Brick | strength of Mortar | Stress Nonuniformity | Net area ratio | Height factor | | | Compression of Masonry Wall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | Mpa | Mpa | | | | | | |
| L | B | H | a | j | fcb | fg | Uu | x | α | f'p | φ | f'm |
| 202 | 103.4 | 43.2 | 23 | 23 | 2.63 | 1.6 | 1.5 | 0.674 | 0.130 | 1.365 | 1.000 | 1.8 |

Stress-strain curve for compressive strength of masonry calculated based on Kaushik [17] and for the tensile strength of masonry based on Chen [18]. (See Fig. 7 and fig. 8)

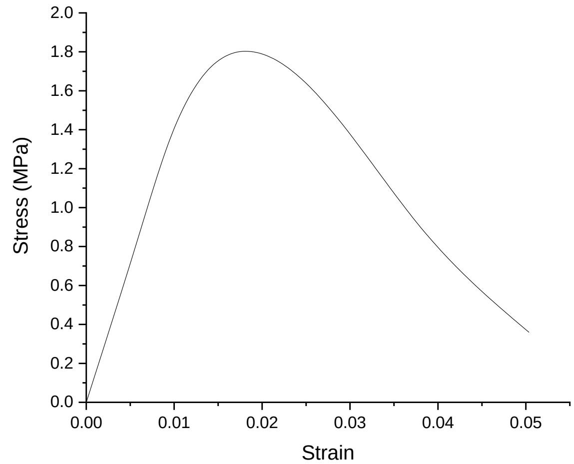


**Fig 7**. Constitutive model in ABAQUS for the Compressive strength of masonry - Kaushik [17]

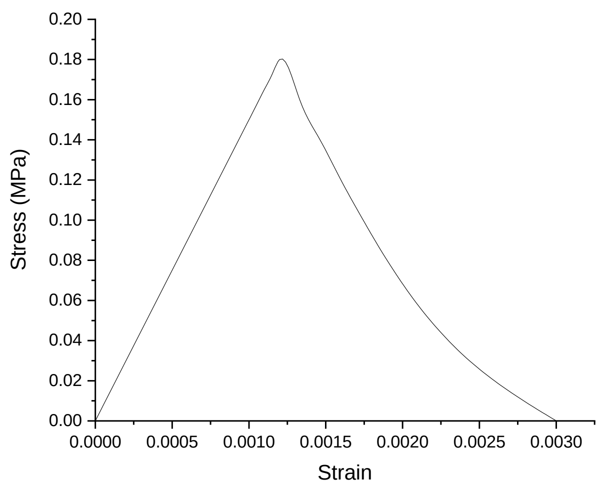


**Fig 8**. Constitutive model in ABAQUS for the tensile strength of masonry - Chen [18]

## 3. Verification of Finite Element Models

Verification of Finite Element Models using experiment Hakas [1]. Model experiment using scale 1:1 with dimensions of 3 x 3 x 0.15 m placed on reinforced concrete slabs. The masonry walls contain concrete frames with beam and column sizes of 0.15 x 0.15 m and there are plastering on both sides with a mortar of 1 PC: 4 Lime: 10 sand. With 2 cm thick. The details of the reinforcement can be seen in Fig. 9. The experiment used 3 LVDT Place in Left Model in the horizontal direction to record lateral displacement and micro vibration testing using the accelerometer to record the frequency of the model masonry wall. See fig. 10 for Experiment set up of Hakas [1]

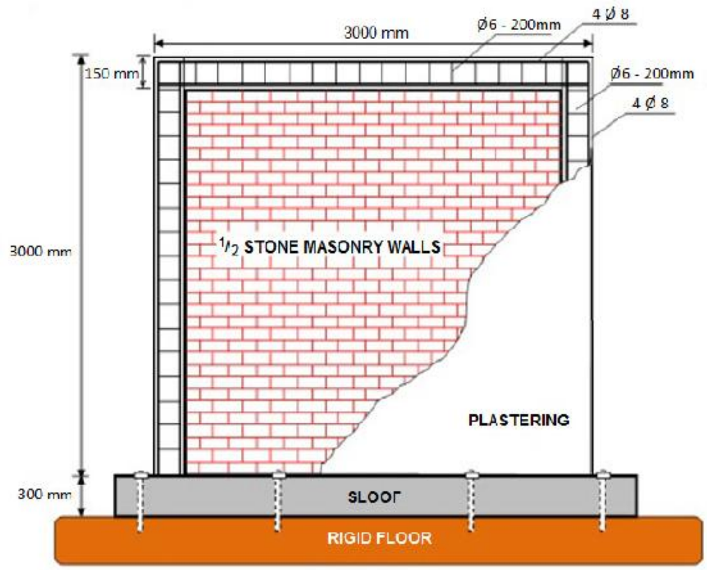


**Fig 9**. A specimen of the wall **-** Hakas [1]

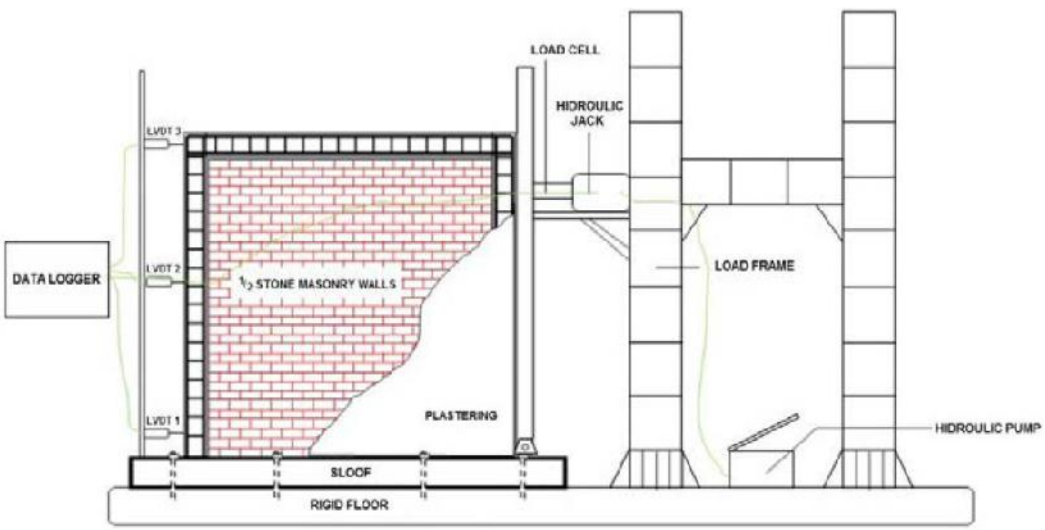


**Fig 10**. Experiment set up of Masonry Wall **-** Hakas [1]

Models of Masonry was given lateral load with the stages of loading which can be seen in table 2.

Table 2. Lateral Force apply in Masonry wall - Hakas [1]

| Load | Load | |
|---|---|---|
| | KN | N |
| Load 1 | 60.84 | 60841.60 |
| Load 2 | 70.25 | 70249.40 |
| Load 3 | 90.16 | 90163.70 |

## 3.1 Verification Result

### 3.1.1 Experiment result in lateral load 90 KN

Fig. 11 shows the load-displacement curve between the Finite element modeling and the Hakas experiment on the lateral force of 90 KN. From the Figure 12 can be seen that the experimental results have the plastic condition at 81 KN load and Finite element modeling have plastic conditions at the load 82.13 KN, there is a difference of 1.4% between the experiment results and Finite element modeling.

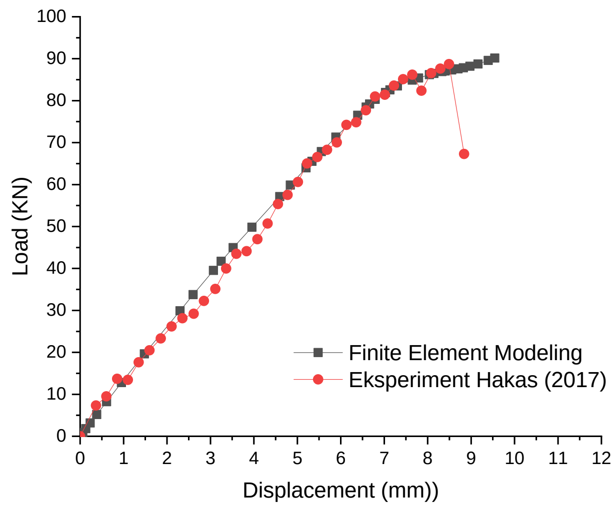


**Fig 11.** The load-displacement curve between the Finite element modeling and Hakas experiment on the lateral force of 90 KN in a solid wall

### 3.1.2 Natural Frequency

Fig. 12 show natural frequency Finite element model in condition without load have 39.625 Hz and in fig. 13 show with load 90 KN have natural frequency 33.12 Hz

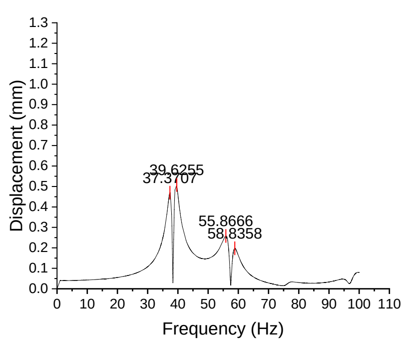


Fig. 12 Frequency-displacement Curve without load condition

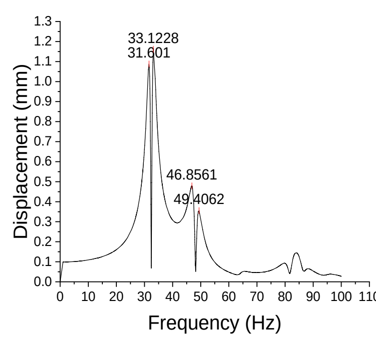


Fig. 13 Frequency-displacement Curve with load 90 KN

Fig. 14 show natural frequency Finite element model in condition 70 KN load have 37.72 Hz and in fig. 15 show with load 60 KN have a natural frequency of 38 Hz

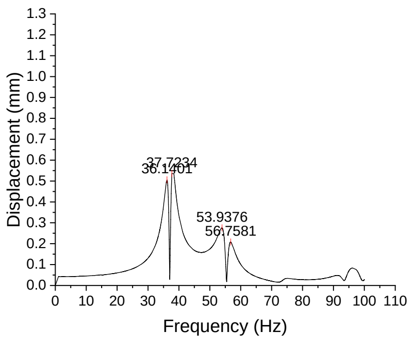


Fig. 14 Frequency-displacement Curve with load 70 KN

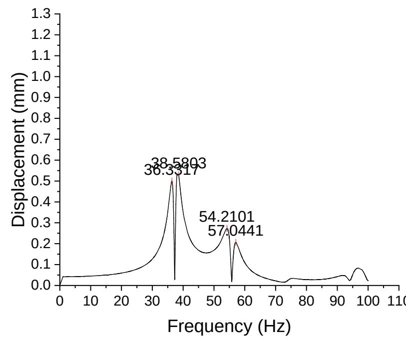


Fig. 15 Frequency-displacement Curve with load 60 KN

Compared natural frequency between the Finite element model and experiment by Hakas [1] can be seen in Table 3:

Table 3. Compared natural frequency between finite element modeling and experiment Hakas (2017)

| No | Condition | Result | | Difference |
|---|---|---|---|---|
| | | Finite Element Modeling | Eksperiment Hakas (2017) | |
| | | Hz | Hz | % |
| 1 | Without Load | 39.62 | 40.58 | 2.37 |
| 2 | Load 60.84 KN | 38.58 | 39.74 | 2.92 |
| 3 | Load 70.25 KN | 37.72 | 38.68 | 2.48 |
| 4 | Load 90.16 KN | 33.12 | 32.43 | 2.13 |

The difference in result between the simulation model of finite element and experiment Hakas (2017) fluctuated between 1.4 % and 2.92 %. The results of verification of the model allow to state that the model of finite element correctly reflects the behavior of masonry under lateral force.

## 4. Variation of Finite Element Model

Model of the finite element will be a variation with the openings in the different area. The openings are placed in the middle of the masonry wall. Variation of area opening wall can be seen in table 4 and fig.16

Table 4. Variation of area opening wall

| No | Type of Masonry | % of area opening wall |
|---|---|---|
| 1 | Solid Wall | 0 |
| 2 | 1 Opening wall | 10 |
| | | 30 |
| | | 50 |
| 3 | 2 Opening Wall | 10 |
| | | 30 |
| 4 | 3 Opening Wall | 10 |
| | | 30 |

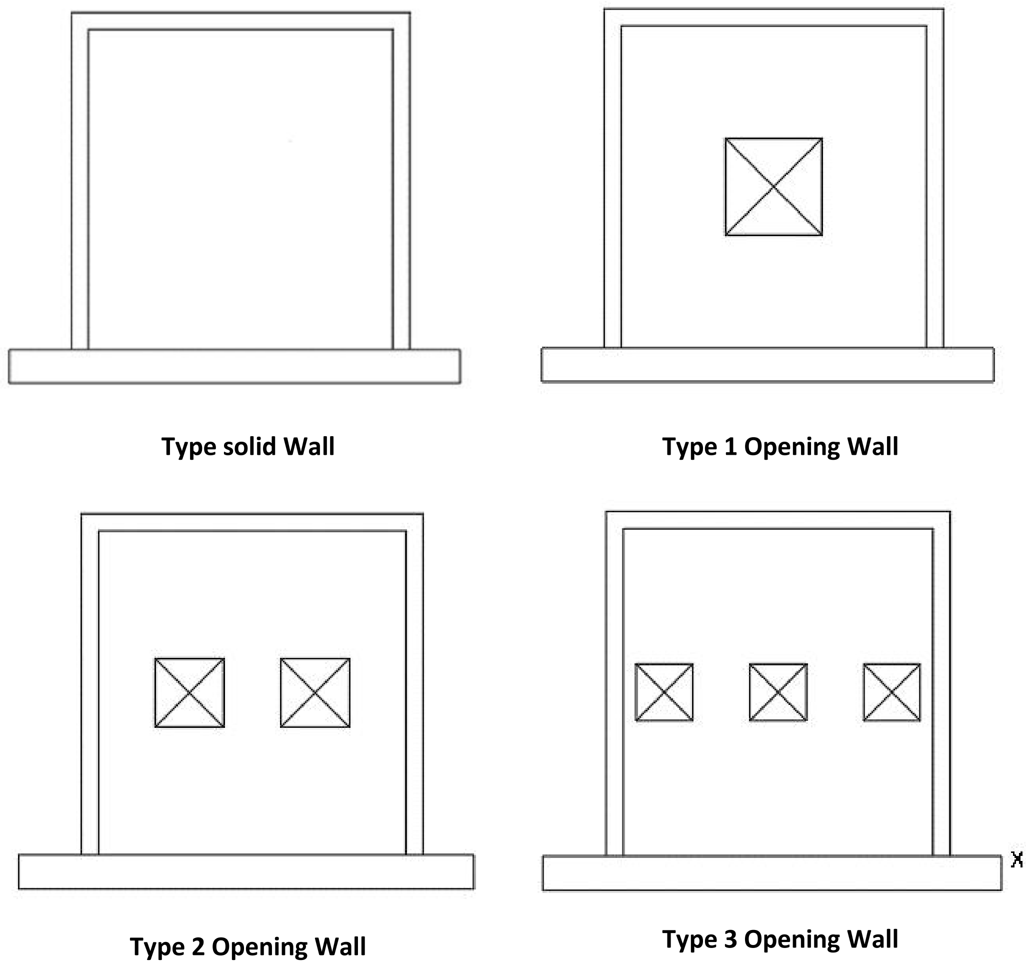


**Fig 16.** Variation of opening wall

## 5. Result

### 5.1 Effects of opening wall

Fig. 17 show the load-displacement curve in 1 opening wall with a different area. From the fig. 17 we can see that increase % of area opening wall make stiffness and strength of masonry wall decrease. Fig. 18 show lateral resistance of masonry wall under lateral force. From fig 18, we can see 10% area of the opening wall will decrease 50.34% lateral resistance of masonry wall and decrease 76.44% in 30% area opening and 85.68% in 50% area opening.

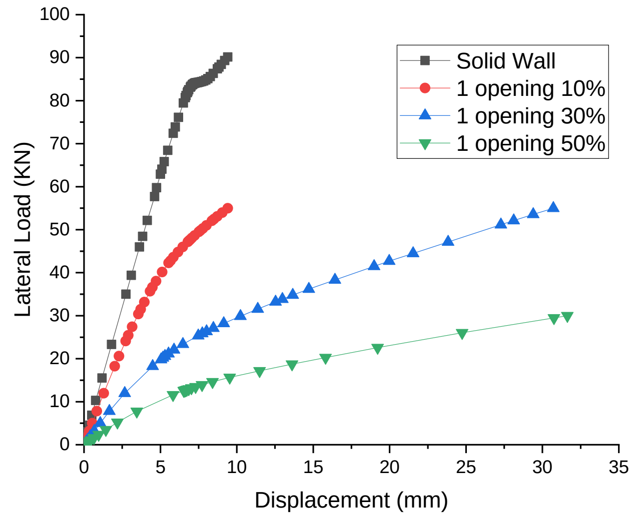


Fig. 17 The load-displacement curve in 1 opening wall

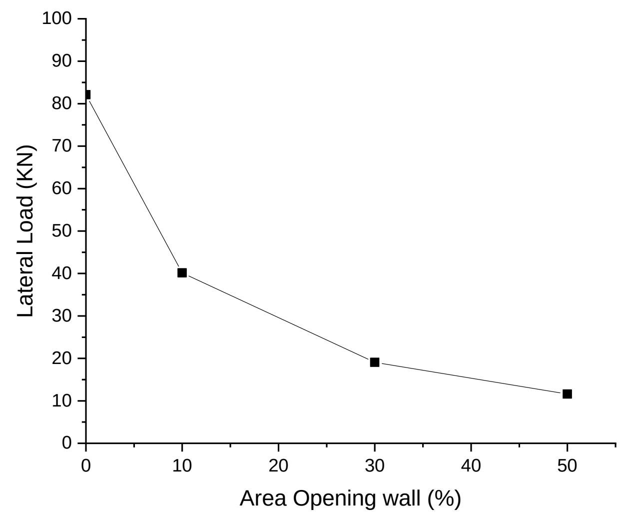


Fig. 18. Lateral resistance of masonry wall with 1 opening

Fig. 19 show the load-displacement curve in 2 opening wall with a different area. In masonry with 2 opening increase % area in the wall make Stiffness and strength of masonry wall will decrease. From the fig. 20 we can see 2 opening wall with 10% of the area will decrease 57.11% lateral resistance of masonry and 30% of the area will decrease 85.8 % lateral resistance of masonry wall

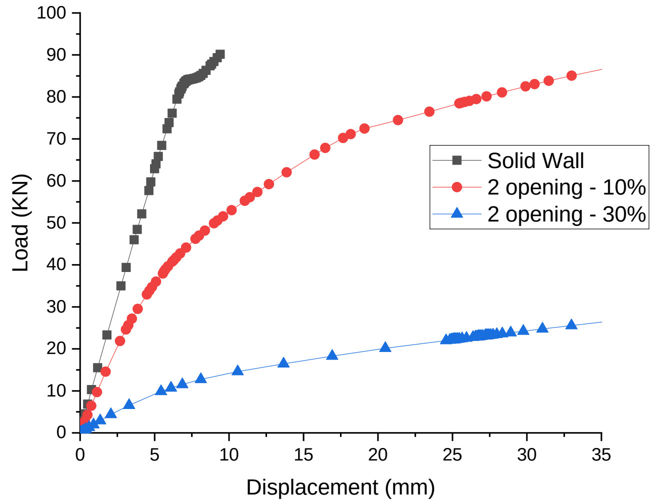


Fig. 19 The load-displacement curve in 2 opening wall

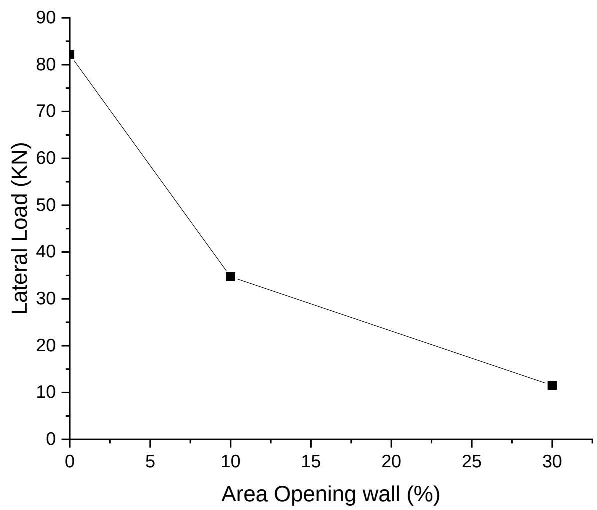


Fig. 20. Lateral resistance of masonry wall with 2 opening

Fig. 21 show the load-displacement curve in 3 opening wall with a different area. From the fig. 22 we can see 3 opening wall with 10% of the area will decrease by 64 % lateral resistance of masonry and 30% of the area will decrease by 87 % lateral resistance of masonry wall

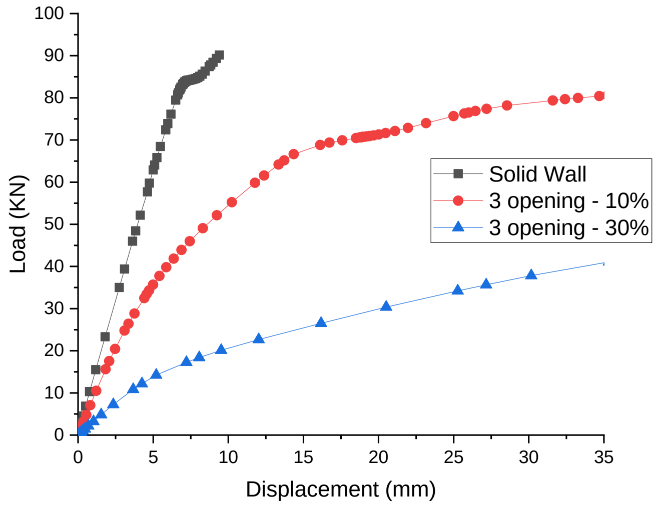


Fig. 21 The load-displacement curve in 3 opening wall

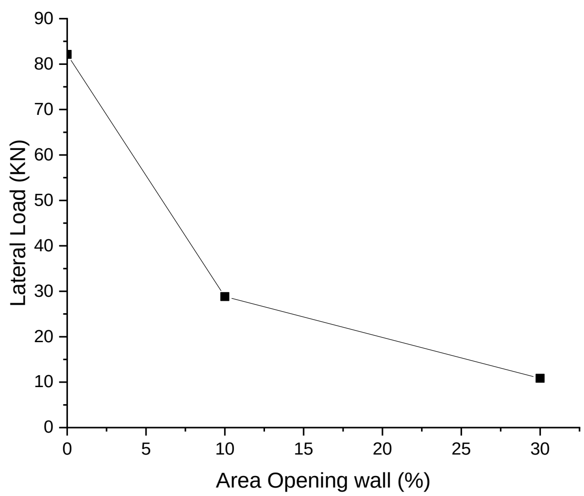


Fig. 22. Lateral resistance of masonry wall with 3 opening

Fig. 23 show the Load-Displacement curve in 10% area opening wall and fig. 24 show Load-Displacement curve in 30% area opening wall. We can see masonry with 10 % of the area opening wall almost have same stiffness even though it has different opening types but in 30% of the opening wall, Stiffness of masonry wall will decrease following the increase of type opening wall

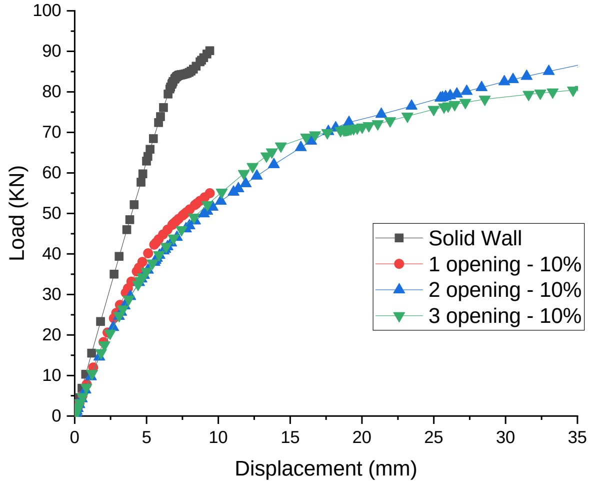


Fig. 23 The load-displacement curve in 10% area opening wall

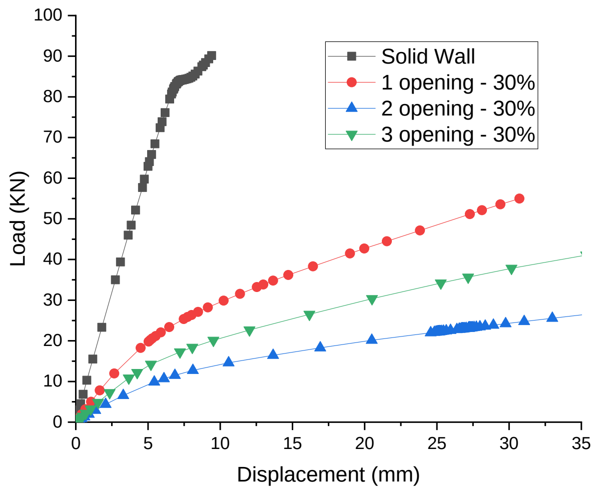


Fig. 24 The load-displacement curve in 30% area opening wall

## 5.2 Finite element damage patterns

Fig 25 – fig 30 show damage patterns in a masonry wall in the difference area. From the figure, we can see damage will begin in column concrete in the bottom of the corner and continue to the masonry wall at the corner of the opening wall. Increase area opening of the wall makes damage of masonry wall bigger.

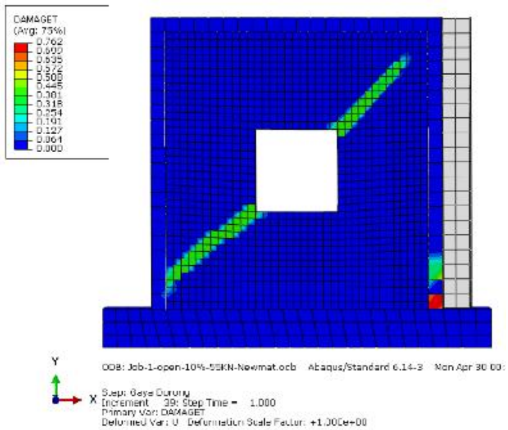


**Fig. 25** Damage patterns in 10% of the area opening wall- type 1 opening wall

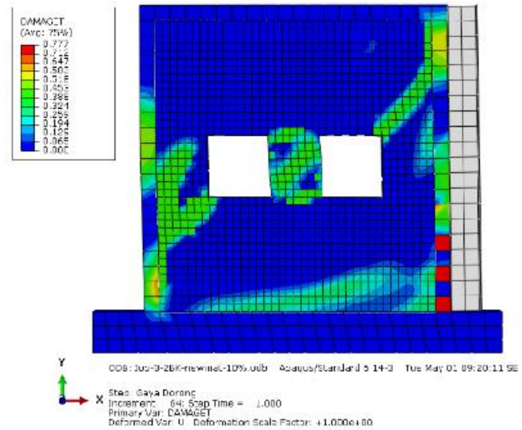


**Fig. 26** Damage patterns in 10% of the area opening wall – type 2 opening wall

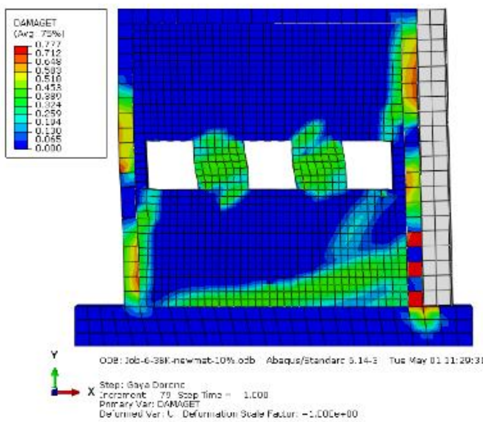


**Fig. 27** Damage patterns in 10% of the area opening wall – type 3 opening wall

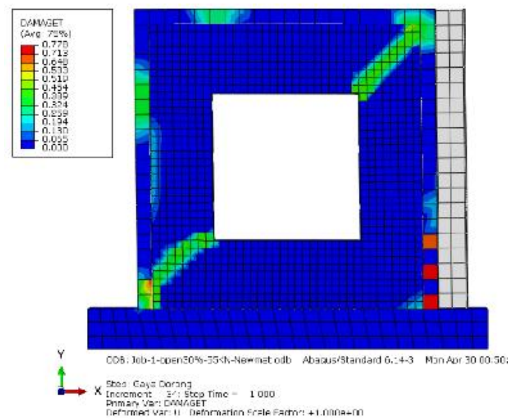


**Fig. 28** Damage patterns in 30% of area opening wall – type 1 opening wall

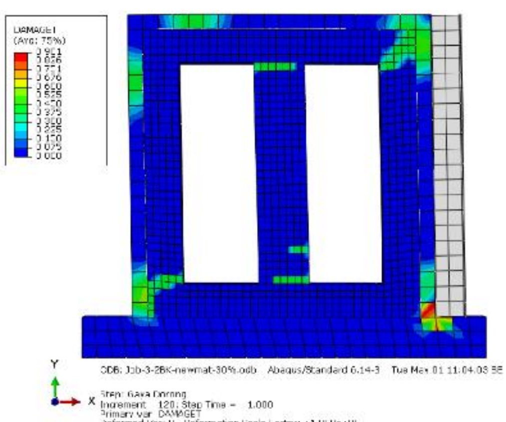


**Fig. 29** Damage patterns in 30% of area opening wall – type 2 opening wall

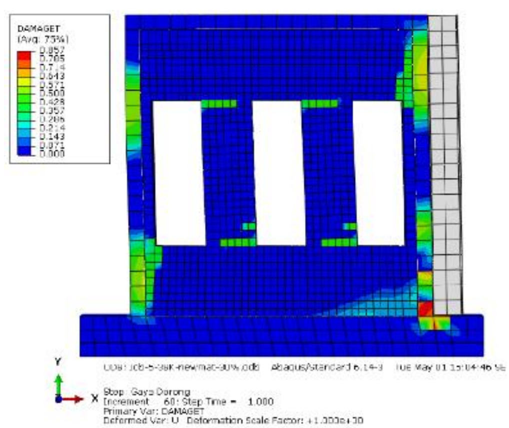


**Fig. 30** Damage patterns in 30% of the area opening wall – type 3 opening wall

## 6. Conclusions

Based on the results of this research, using integrated modeling Finite Element Models of an opening masonry wall with the ABAQUS software. The obtained results are discussed:

1. The Finite Element model using the ABAQUS Software can represent the load-displacement curve of Masonry walls under lateral forces.
2. Increase area opening wall make stiffness and strength of the masonry wall decrease.
3. A masonry wall with a type of 1 opening, In lateral resistance, will decrease were 50.34%, 76.44%, and 85.68% respectively for each area of the opening wall
4. A masonry wall with a type of 2 opening, In lateral resistance, will decrease were 57.11%, and 85.8% respectively for each area of the opening wall
5. A masonry wall with a type of 3 opening, In lateral resistance, will decrease were 64%, and 87% respectively for each area of the opening wall
6. Masonry with 10 % of area opening wall have the same stiffness even though it has different opening types
7. Masonry with 30 % of area opening wall, Stiffness of masonry wall will decrease following increase of type opening wall

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